SENSORIAL INTERFERENCE AVOIDANCE BY MULTI MOBILE ROBOT SENSOR COORDINATION

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Abstract: One way to automate dangerous work at construction sites, could be to use mobile robots able to move around the framework of a building or a road. This paper presents an algorithm, which permits synchronization of active sensors, such as ultrasonic sensors, IR, laser, etc., firing and reception of signals in the presence of several mobile robots working in the same environment. These sensors base their measurement on the transmission and reception of signals; these can interfere mutually giving rise the erroneous measurement. The proposed algorithm is intended to eliminate this interference between signals fired from different robots operating in the same zone, establishing a firing sequence. Various experimental results show the effectiveness of the presented method.

Keywords: Mobile Robots, Sensor Coordination, Sensor Interference

1 INTRODUCTION

Building and roadway construction represents a considerable potential for applying mobile robotics technology. The repetitive nature, the unsafe conditions and the increasing traffic volume are some good reasons for the robotization of building and road construction. Activities involved included surveying, excavation, loading and dumping earth material. When robots operating in the same indoor or outdoor environment are equipped with active sensors (ultrasonic sensors, IR, laser, etc.) [1] [2], that is to say, sensor that base their measurement on the transmission and reception of signals, these can interfere mutually giving rise to erroneous measurement which provoke the robots to collide or run into object found in their trajectory.

The behavior of this type of sensor as their limitations is widely described in the literature. In [3] a navigation algorithm which utilizes matches between observed geometric beacons an a priori map of the environment is presented. They use a mobile robot with six fixed ultrasonic sensors in a ring formation to provide range information. A.de la Escalera *et al.* [4] use a combination of a laser diode and a CCD camera; the sensorial information is modeled in order to obtain an occupancy grids solution. A.Fusiello *et al.* [5] present a mobile robot equipped with ultrasonic range finders; the robotic system is able to autonomously explore indoor environments. In [6] the influence of sensitivity and directivity in ultrasonic sensor information is studied. They have constructed two ultrasonic ranging systems and examined their performance such as obstacle detectability and resultant sonar map.

Several algorithms have been development in order to permit the selection of reliable information or to eliminate those which can be erroneous. J.Borenstein *et al.* [7] have proposed the EERUF method (eliminating rapid ultrasonic firing) for firing multiple ultrasonic sensors in mobile robot applications. EERUF allows ultrasonic sensors to fire at rates that are some times faster that those customary in conventional applications. The method allows multiple mobile robots collaborating in the same environment, even if their ultrasonic sensors operate at the same frequencies. In [8] a method to solve the problem of reflections designations as the specular reflection probability method is propcsed, and K.Kawabata *et al.* [9] propose the distance measurement method.

Interferences may not only appear between sensors belonging to the same robots, but also between sensors from several mobile robots operating in the same space. The algorithm proposed in this paper has been designed to avoid mutual interference between sensor belonging to several robots by coordination of their sensors firing. To ensure this coordination the robots must communicate information to each other. Mobile robots synchronize their sensor firing through the transmission of tokens. This technique is inspired from the token bus Medium Access Control [10]. The communication between robots is achieved by radio using sockets. It is a socket based communication and message exchange protocol [11] that permits the dialogue between devices connected on the network.

The robots control is distributed into a single coordinator and several cooperators. In [12] an organization method for a collaborating team of robots is presented. They have developed a distributed autonomous robotic system, which is composed of multiple robotic agents. All robots in the system broadcast their positions and determine those which are in the range of action of their sensors, and generate with them a group of bind.

In many systems the priority is employed as an important parameter to decide which task should be accomplished first, which robot must accomplish an operation sooner, etc. In [13] a concept of the self-recognition for the decision making of the behavior in a robotic group is proposed. T.Ueyama *et al.* [14] have been developed a hierarchical control architecture of mobile robots based on a number of robotics units called cells.

2 SENSOR COORDINATION

When several mobile robots are operating in the same environment equipped with active sensors like IR, ultrasonics, laser etc. it is necessary to synchronize their firing sensor. This involve that the mobile robots decrease their velocity due to their firing frecuency decrease too.

2.1 *Sensors interference.*

The robots which sensors interfere form a group of bind. These requiere synchronising their sensor firing. There are two main factors which influence in the number of groups of bind. The first is the number of robots that they move in the same environment. The higher is the number of robots the higher is the probability that a group of bind is formed. The second factor is the range of sensors. The higher is the range of sensors the higher is the probability that a group of bind is generated.

The problem is more complex when those factors increase.

2.2 *Multi-group coordination.*

It can occur that a robot belong to several groups of bind. In this case the problem increases complexity because not only we have to synchronize the sensor firing of robots which belong to a group of bind but we have to synchronize the sensor firing of robots which belong to other. We call to this case metacoordination formed by one, two, three etc. groups of bind.

2.3 *Priority.*

An important parameter that influences on the order of the firing sensor is the priority. Depending on the situation of robot a value of priority can be assigned to it. The solution adopted by ours is: priority 2 when the robots is executing a task, is transporting a object or is with low battery; and priority 1 when the robot is moving without any load. The robots with higher value of priority have more preference on firing their sensors.

2.4 *Coordinator.*

Once that we know the robots that they form the different groups of bind or metacoordination we have to select the coordinator. This coordinator has to generate the firing sequence sending to the other robots of the metacoordination the order to fire their sensors. There is one coordinator by each group of bind or metacoordination. The solution adopted to choose the coordinator is to select the robot which belongs to several groups of bind. If several robots comply with the previous requirement, you select the robot of them with the highest value of priority. If the previous criterion is insufficient, it is selected the robot with the smallest number identification. More requirements are not necessary because there are not two robots with the same identification number.

2.5 *Firing frequency*

When a group of bind is formed by a lot of robots, their firing frequency decrease. This implies that the known on the environment decrease. We can say that the firing frequency of a robot is equal to:

$$f = \frac{priority\ of\ robot\ i}{SUM\ PRIORITIES} \tag{1}$$

where SUM PRIORITIES is the sum of priorities of robots which belong to the same group that the robot i.

Due to it is necessary to decrease the velocity of robots to avoid that they collide with objects, persons or with other robots. The velocity decreases proportionately with the firing frequency.

We development an algorithm which permits to synchronize the firing sensor of the mobile sensor.

2.5.1 *Firing sequence.*

Let is suppose that the situation that is shown in the figure 1 occurs, there are three robots whose

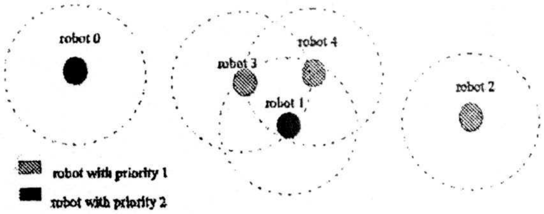

Figure 1: Firing sequence

sensors interfere (robots 1, 3 and 4). These three robots belong to the same group of bind, the robot number 1 being the coordinator, since is the one which has the greatest priority. The sensors of the robots 0 and 2 does not interfere with any other belonging to other robot, so they do not belong to any group of bind. The firing sequence is the following:

1-3-1-4/1-3-1-4/.....
0-0-0-0/0-0-0-0/.....
2-2-2-2/2-2-2-2/.....

The firing of the robot 1 is alternated, since if it would be continous: 1-1-3-4/1-1-3-4/... the time elapsed between the second firing of the first sequence and the first firing of the second one would be increased, reducing its knowledge of the environment and the robots become unable to avoid colliding. However the time elapsed between the first firing and the second of the first sequence would be very short. One must obtain a balance, in such a way that the firing frecuency of a robot will be equal or very similar during the complete synchronisation process.

3 ALGORITHM.

Before generating the groups of bind it is necessary to establish the communication between the mobile robots. Then each robot broadcasts its position and receives those of others. When the robots have all positions from the rest of robots calculate the groups of bind and select the coordinator.

The coordinator from each group of bind or metacoordination generate the firing sequence. It sends a message *fire* to the robot which has to fire its sensor and a message *no-fire* to the rest of robots of its group of bind or metacoordination. The robots which are not the coordinator act as slaves receiving the messages from the coordinator.

If the number of robots of a group of bind is very big can occur that their velocity decrease very much. To avoid this a solution adopted by ours is to stop some robots. When the number of robots of a group of bind decrease then these robots begin move. The solution adopted to stop

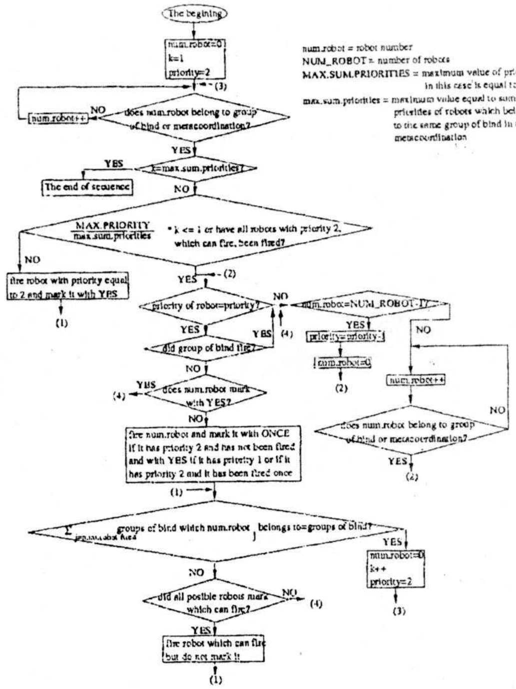

Figure 2: Algorithm

some robots is: to stop the robot with the slowest priority value. If several robots comply with this requirement then to stop the robot with the highest identification number.

Each time one must check the new distance between the robots to determine if there is interaction or not. This is due to that different situations can produce:

- A new group of bind which there were not before is generated. In this case a robot will be the coordinator and the rest of robots will be the slaves.
- A robot or several robots are incorporated into an already existing group. In this case can occur that the coordinator change or not.
- A robot leaves a group of bind. If this robot was the coordinator, now other robot will be it of this group.

In all cases the firing sequence change and it is necessary to calculate again.

The flow diagram is shown in the figure 2.

3.1 *Description of algorithm*

When the communication is established between all robots, they broadcast their position generating the groups of bind and metacoordinations. From each group a coordinator is selected. This coordinator generates the firing sequence and the rest of robots of this group act as slaves waiting for the coordinator send the order to fire their sensors.

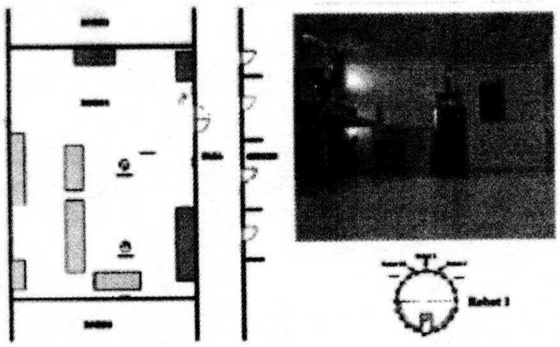

Figure 3: Indoor environment

The number of the firing sensors in a sequence is equal to the sum the priorities of the group of bind that it has this value maximum. In case of metacoordination we must consider each group of bind separated. Each robot has to fire its sensors in a sequence equal to its priority value.

In the firing sequence the firing sensors of one robot has to be the most equidistant as possible.

4 EXPERIMENTAL RESULTS

All experiments have been conducted on two B21-RWI mobile vehicles (figure 4), equipped with a peripheral ring of 24 ultrasonic sensors and 24 IR sensors, in order to work in indoor environments (figure 3), and a Modulaire mobile robot (figure 5), equipped with a scanning laser range finder, to work in outdoor environments. The mobile robot architecture is based on a hybrid architecture AFRED (Adaptative Fusion of Reactive Behaviors) approach with a wide range of reactive control methodologies [15]. Interference between the sensors of several robots occurs when they are at a distance below 20 m. We have performed experiments putting the mobile robots at different distances and checked for interferences when the sensor are fired simultaneously. The ultrasonic sensor information is refreshed every 200 msec during the navigation process. The results presented in the figure 6 and 7 are for a distance of 3.5m and taking 500 samples of each sensor from robot 1 in figure 3. Figure 6 shows the data of the sensors when they are fired separately or synchronised, while figure 7 shows the data when sensors are fired at the same time. In both figures the x axis represents the number of sensors (there are 24 ultrasonic sensors) and the y axis represents the values obtained by each sensor. The latter values are shown in percentage of half the sensor range and not in distance. In another words a 100 on the y axis is translate to a distance of 10m.

The sensors 10, 11, 13, 15 and 16 provide values that more scattered (figure 7) when the two robots are fired simultaneously than when they are fired in separately (figure 6). This implies that interference exists and sensor sinchronisation is a neccesary operation. Also we have proved in our laboratory the hardiness of our algorithm concerning communications, in such a way that we have forced the failure in a robot and observed that this is stopped while the rest of robots continue with the process. When the problem is solved the robot is incorporated into process again.

Figure 4: RWI Mobile Vehicles

5 CONCLUSIONS

We have introduced an algorithm which prevents

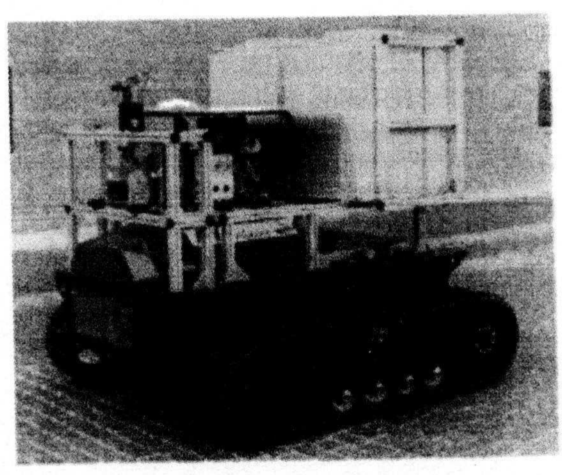

Figure 5: Modulaire Mobile Robot

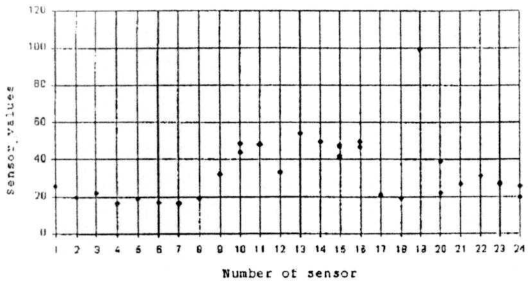

Figure 6: Data of sensor when they are fired separately or synchronized

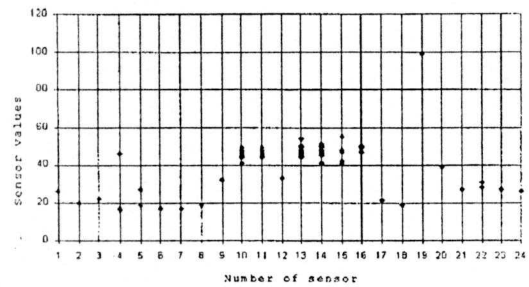

Figure 7: Data of sensor when they are fired at the same time

the sensors belonging to different robots from interfering. This is accomplished by sinchronising their firing, so that the sensors of the robots which are close are not fired simultaneously. This allows several robots to operate in the same zone without colliding. This algorithm does not eliminate wrong data, but simply prevents situations when the sensors may interfere. On the other hand, it is a robust algorithm to failures in such a way that if a failure is occurred in the communications the robots will not remain moving without any type of control, with the risk that this implies. The other advantages of this algorithm is that it can be used to synchronize the firing of different types of active sensors. The fact that the number of robots to synchronize is not prefixed offers the algorithm more flexibility and allows a larger number of robots to operate in the same area.

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References

[1] Yuta, Shin'ichi, Shooji Suzuki, Yuichi Saito and Sigedi Iida (1991). Implementation of an active optical range sensor using laser slit for indoor intelligent mobile robot. In: *IEEE / RSJ International Workshop on Intelligent Robots and Systems IROS'91.* Japan. pp. 415–420.

[2] Gimenez A., C. Balaguer, J.M. Pastor, V.M. Pastor and M. Adderrahin (1998). Design and path-planning for a climbing robot able to travel along 3D metallic structures.*First International Symposium CLAWAR.* pp. 161-166.

[3] Leonard, J.J. and H.F. Durrant-White (1992). *Directed Sonar Sensing for Mobile Robot Navigation.* Kluwer Academic.

[4] Escalera A. de la, M.A. Salichs, L. Moreno and J.M Armingol (1994). Perception in non-structured environments using active vision. In: *IFAC Artificial Intelligence in Real-Time Control AIRTIC'94.* Valencia, Spain. pp. 341–346.

[5] Fusiello A., Caprile B. "Synthesis of indoor maps in presence of uncertainty". Robotics and Autonomous Systems, Vol. 22, pp 103-114. 1997.

[6] Ohya, Akihisa, Takayuki Ohno and Shin'chi Yuta (1996). Obstacle detectability of ultrasonic ranging system and sonar map understanding. *Robotics and Autonomous Systems 18* pp. 251–257.

[7] Borenstein, J. and Y. Koren (1995). Error eliminating rapid ultrasonic firing for mobile robot obstacle avoidance. In: *IEEE Transactions on Robotics and Automation.* Vol. II. pp. 132–138.

[8] Lim, Jong Hwan and Dong Woo Choo (1992). Physically based sensor modelling for a sonar map in a specular environment. In: *IEEE International Conference on Robotics and Automation.* Vol. II. Nice, France. pp. 1714–1719.

[9] Kawabata, K. and et al. (1996). Distance measurement method under multiple ultra sonic sensors environment. In: *Proc. IECON'96.* Vol. II. p. 812.

[10] Standars, An American National (1995). *IEEE Standars for Local Area Networks: Token-Passing Bus Access Method and Physical Layer Specifications.*

[11] Giuffrida, F., G. Vercelli and R. Zaccaria (1994). *A Multi Agent Distributed Host to Robot Real-Time Communication Environment.* Springer-Verlag.

[12] Ozaki, K., H. Asama, Y. Ishida, K. Yokota, A. Matsumoto, H. Kaetsu and I. Endo (1994). *Negociation Method for Collaborating Team Organization among Multiple Robots*. Springer-Verlag.

[13] Fukuda, T. and G. Iratini (1994). *Intention Model and Coordination for Collective Behaviour in Group Robotic System*. Springer-Verlag.

[14] Ueyama, T., T. Fukuda, A. Sakai and F. Arai (1994). *Hierarchical Control Architecture with Learning and Adaptation Ability for Cellular Robotic System*. Springer-Verlag.

[15] Salichs, M.A., E.A. Puente, L. Moreno and J.R. Pimentel (1993). *A Software Development for Autonomous Mobile Robots*. World Scientific.